N66 32949

THE USE OF RADIATION SHIELDS FOR THERMAL CONTROL OF VEHICLES ON THE LUNAR SURFACE

John C. Arvesen
Ames Research Center
Moffett Field, California

INTRODUCTION

For the past several years Ames Research Center has been involved in determining methods of thermal protection for vehicles that have to travel very close to the sun, such as a Solar Probe. One thermal control method that has proven to be very effective is the use of solar radiation shields. It is known that a vehicle traveling from the earth to within a tenth of an astronomical unit from the sun will be exposed to an intensity level of over 100 solar constants. It was shown in reference 1 that if this vehicle is shielded from direct solar radiation, its temperature change can be held to less than 10° F. An unshielded vehicle, by comparison, would increase in temperature hundreds to thousands of degrees, depending upon the solar absorptance and emittance properties of its surface. Since shields were so effective in isolating this particular vehicle from solar radiation, a study was undertaken to extend a similar concept to the protection of vehicles on the surface of the moon. The complete results of this study are reported in reference 2 and the main points will be presented in this paper.

LUNAR ENVIRONMENT

Much is known about the thermal environment of the moon as a result of astronomical measurements. The temperature variation and the reflectance and emittance properties are known fairly accurately. It is also known that the thermal conductivity of the surface is lower than any natural material found on earth. This last fact, along with the complete absence of any atmosphere, makes thermal radiation the primary mode of heat transfer for vehicles on the lunar surface.

Probably the most widely accepted lunar surface temperature measurements have been made by William Sinton and his associates at Lowell Observatory. These measurements are shown in figure 1.

This figure shows the temperature variation at the equator during one complete lunar day. Even though the solid curve is an approximation that assumes zero thermal inertia of the surface material, it agrees well with the measured temperature points. The most significant fact to be noted is the extremely large temperature variation during the day. At the subsolar point the surface temperature is about 240° F. As the day goes on, the temperature drops until it reaches a value of -240°F after the sun sets.

UNSHIELDED VEHICLE

During the daytime a vehicle will be receiving a large amount of radiation from the hot lunar surface. This radiation level is particularly high if the vehicle is at or near the subsolar point. Other major sources of heat that will contribute to the temperature of a vehicle on the lunar surface are direct solar radiation, solar radiation reflected from the lunar surface, and internally generated heat.

Direct solar radiation is one of the largest heat inputs to the vehicle. For vehicles with a high ratio of solar absorptance to emittance, the level of direct solar radiation will probably be the main factor in determining the vehicle's temperature. Solar radiation that is reflected from the lunar surface onto the vehicle will usually be of secondary importance, since the reflectance of the lunar surface material is only about 7 percent. For vehicles with a low α_s/ϵ coating, such as white paint, the main heat inputs will be radiation emitted from the lunar surface and internal heat. In order to evaluate the effects of these heat inputs on the temperature of a lunar vehicle, a particular configuration was chosen for study. This vehicle is shown in figure 2.

The design of the vehicle is very simple but the results obtained may be applied to more complex ones. The vehicle consists of a 60° conical section on top of a cylindrical body. It is assumed to be resting on a non-conducting support so that the only mode of heat transfer between it and the lunar surface is by radiation. There is also assumed to be no heat conduction between each section of the vehicle.

Subsolar Point

When the vehicle is at the subsolar point the conical section will receive direct radiation from the sun while the cylindrical

section will have no direct solar radiation incident. However, the cylindrical section will be exposed to radiation leaving the lunar surface to a greater degree than the conical section. The resulting temperature on each section for no internal heat is shown in figure 3. In this figure the surface temperatures are shown as a function of the vehicle's α_s/ϵ ratio, which varies from 0.1 to 10.0. Since the conical section has such a high level of solar radiation incident upon its surface, its resulting temperature is very dependent upon this α_s/ϵ ratio. For materials such as polished metals, temperatures may reach 300° F to 400° F.

The temperature of the cylindrical section, on the other hand, is relatively independent of the α_s/ϵ ratio since very little solar radiation is incident. It should be noted, however, that just the heat received from the lunar surface is enough to give an undesirably high temperature on this section, regardless of what its surface properties are. It should also be noted that unless a very stable white coating is used on the conical section its temperature will also be high.

Side Illumination

A unique situation is encountered if the sun is on the horizon, as would be the case if it were lunar dawn, dusk, or if the vehicle were at either pole. One side of the vehicle would receive the full intensity of the direct sun, while the other side would be in darkness.

If the heat conduction in the skin of the vehicle is assumed to be zero, the temperature distribution around the circumference of the cylindrical section will be as shown in figure 4. It can be seen that severe thermal gradients and large temperature differences may occur between the sunlit and shaded sides, especially at the higher values of α_s/ϵ. Heat conduction in the skin of the vehicle will help the situation but the effect is not really significant, as can be seen in figure 5. In this figure the vehicle is assumed to be 10 feet in diameter with an α_s/ϵ ratio of 1.0. The upper dashed curve represents a relatively high conductance skin of 1/8-inch thick aluminum. The other curves represent fractions of this value down to zero. The main effect is a temperature increase on the shaded side of the vehicle. However, the sunlit-side temperature remains relatively unchanged and there is still a large temperature difference from this side to the shaded side.

SHIELDED VEHICLE

Three different shield configurations were considered for use at the subsolar point and are shown in figure 6. The small shield (figure 6(a)) is the same diameter as the vehicle and does not shade the lunar surface. The next configuration (figure 6(b)) has a much larger shield which will shade and cool the surface of the moon within its shadow. The heat input from the lunar surface may be reduced by means of a shield that is symmetric around the base of the vehicle (figure 6(c)). Radiation emitted from the lunar surface will strike the shield and be reflected back. This shield is completely shaded by the large solar shield so that no direct sunlight will hit it. All these shields could be made fairly lightweight and might consist merely of a coated plastic film. The surface properties of these shields were found to be not particularly important so that if they were to undergo degradation there would be only a secondary effect upon the vehicle's temperature.

It is difficult to calculate the temperatures of a shielded vehicle because of the large number of surfaces involved. It must be considered that each surface could have different values of solar absorptance and emittance, as is the case for real materials. In order to have reasonable accuracy, infinite reflections between all surfaces must also be included. In reference 2 a general analysis was developed and was programmed for solution on an IBM 7090 computer. This computer program was then used to determine the effectiveness of the various shield configurations in reducing the temperatures of the two sections of the vehicle.

Subsolar Point

The temperatures on the conical section of the shielded vehicle are shown in figure 7(a). The unshielded case, as shown before, is very dependent upon the α_s/ϵ ratio and will reach temperatures that are much too high unless a very low ratio is used. For all shielded configurations the amount of solar radiation reaching this section has been almost entirely eliminated and, as a result, the temperature is almost independent of the α_s/ϵ ratio. Even at high values, the temperature is down to a reasonable level. This is important because it means that the surface of the vehicle could degrade badly from some environmental effect and the temperature would be unaffected.

The effect of shields upon the temperature of the cylindrical section is shown in figure 7(b). At the subsolar point the small

solar shield, which is the same diameter as the vehicle, has no effect on the cylindrical section. When the larger shield is added, the lunar surface around the vehicle will be shaded and cooled and the temperature of the cylindrical section will be correspondingly reduced. The main heat input is now from the hot lunar surface. By adding the lunar radiation shield around the base of the vehicle even this component can be effectively eliminated. Thus, by using shields, the temperature of this section at the subsolar point can be reduced to below -100° F. This level is probably too low for most applications but it should be apparent that the shields can be easily arranged to give almost any desired temperature between the unshielded and completely shielded limits. Internally generated heat will, of course, raise all temperatures.

Side Illumination

It was previously shown that a vehicle may have a large temperature difference from one side to the other when the sun is near the horizon. A solar shield is particularly useful here as can be seen in figure 8. In this figure, a single shield is placed between the vehicle and incident solar radiation. The temperature of the shielded side and the back side of the vehicle is shown as a function of the shield's separation distance. As the shield is moved farther away, the heat radiated to the vehicle becomes less and less until it approaches the level on the back side of the vehicle. Again, internal heat can be used to maintain the desired temperature level.

CONCLUDING REMARKS

This paper has attempted to show how effective shields can be in eliminating some of the problems that may be encountered when vehicles are on the surface of the moon. There is also no reason why a shield cannot be used by a man outside of the vehicle to reduce the solar and infrared heating of his spacesuit. In effect, solar shields are nothing more than the parasols that women have been using for years. The simplicity and versatility of radiation shields makes them an ideal safety measure, for both man and vehicle, in case of some unforeseen emergency. In conclusion, shields are an answer to most situations where a high degree of isolation from an external thermal environment is required.

REFERENCES

1. Nothwang, George J., Arvesen, John C., and Hamaker, Frank M.: Analysis of Solar-Radiation Shields for Temperature Control of Space Vehicles Subjected to Large Changes in Solar Energy. NASA TN D-1209, 1962.

2. Arvesen, John C. and Hamaker, Frank M.: Effectiveness of Radiation Shields for Thermal Control of Vehicles on the Sunlit Side of the Moon. NASA TN D-2130, 1964.

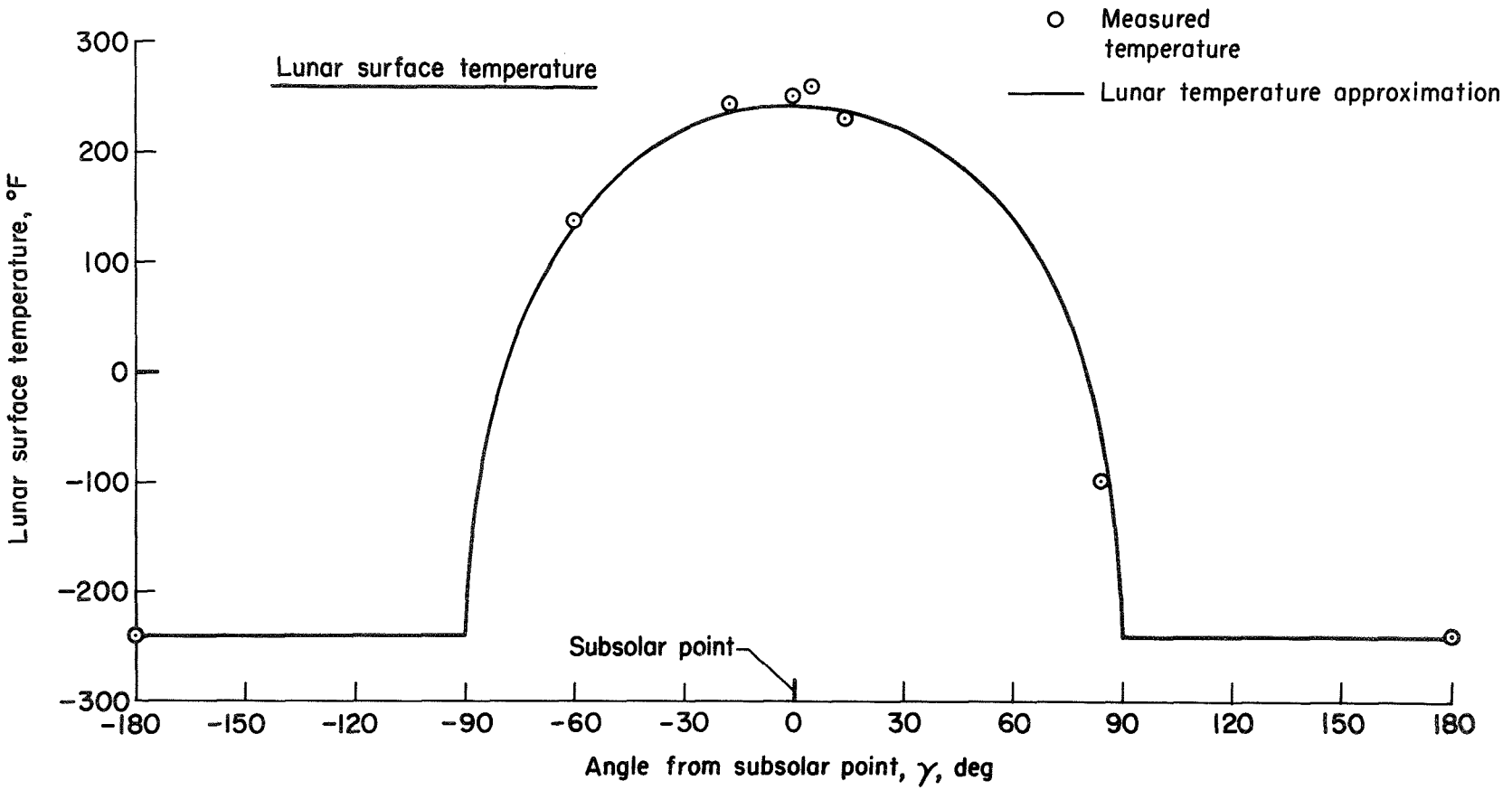


Figure 1. - Temperature variation of the lunar surface.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
AMES RESEARCH CENTER, MOFFETT FIELD, CALIFORNIA

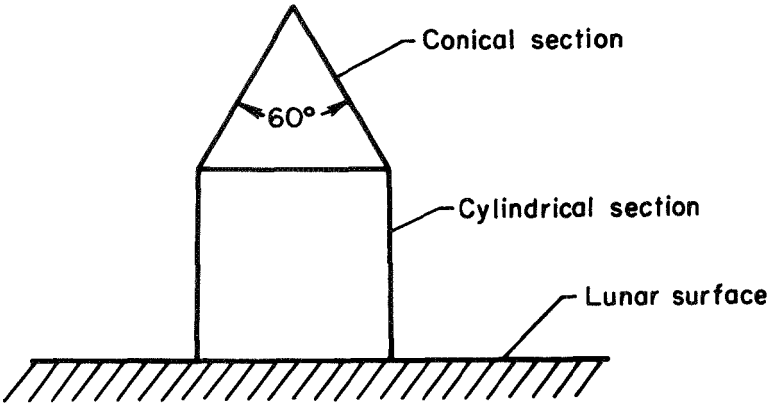


Figure 2. - Basic vehicle configuration.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
AMES RESEARCH CENTER, MOFFETT FIELD, CALIFORNIA

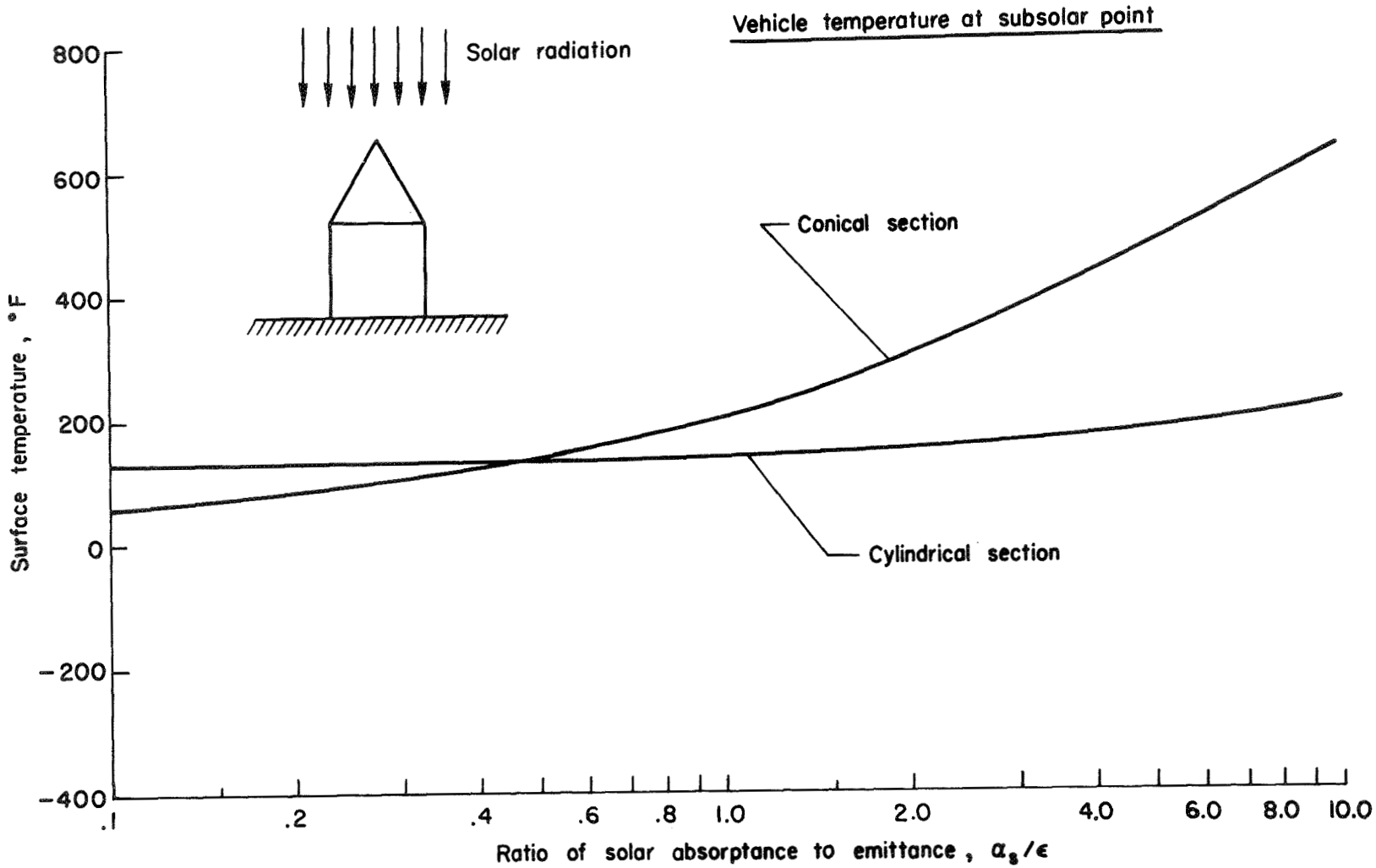


Figure 3. - Effect of the ratio of solar absorptance to emittance on the surface temperatures of the unshielded vehicle at the subsolar point; conductance and internal heat both zero.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
AMES RESEARCH CENTER, MOFFETT FIELD, CALIFORNIA

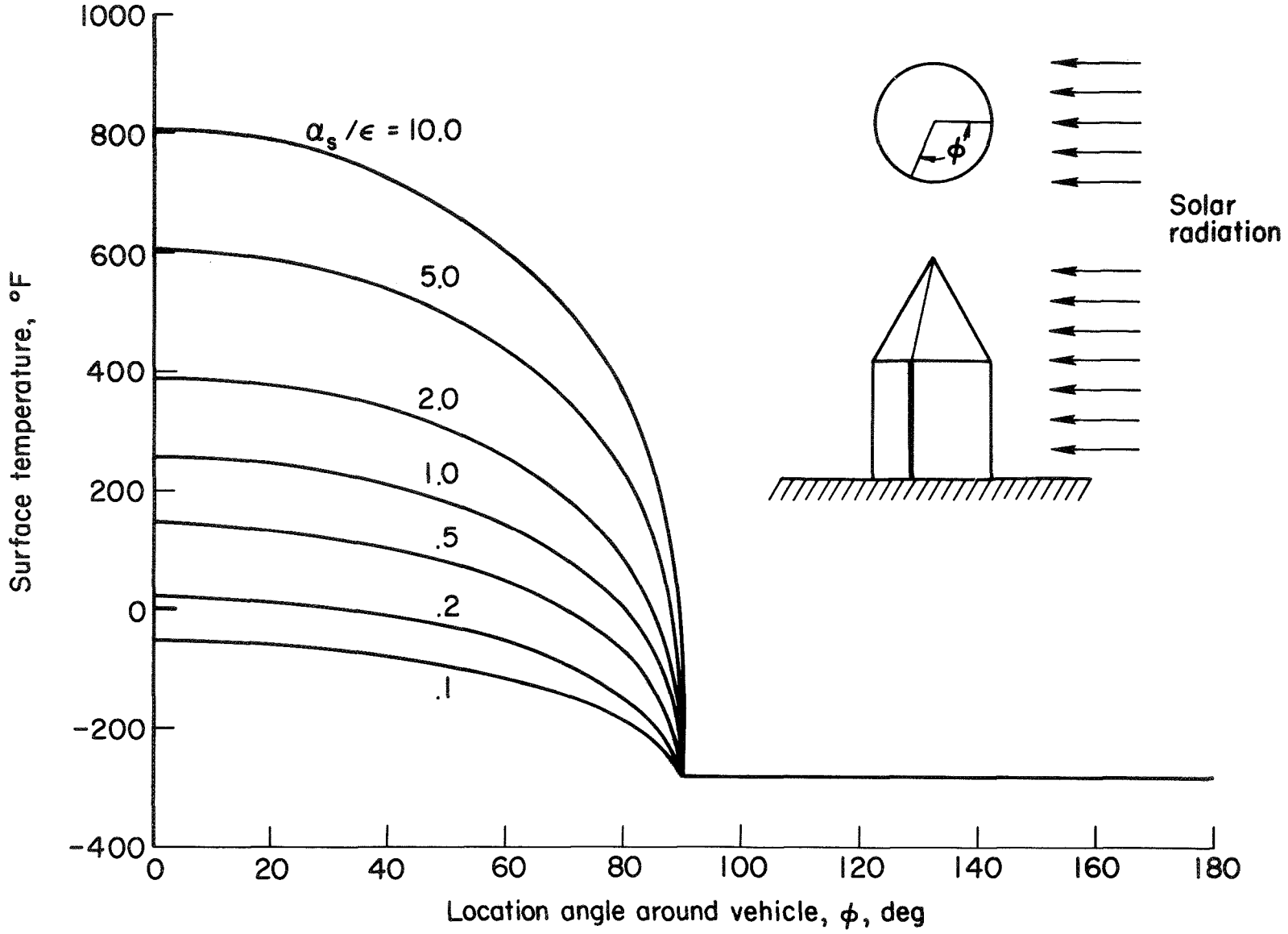


Figure 4. - Temperature variation around the cylindrical section of the unshielded vehicle when illuminated from the side; conductance and internal heat both zero.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
AMES RESEARCH CENTER, MOFFETT FIELD, CALIFORNIA

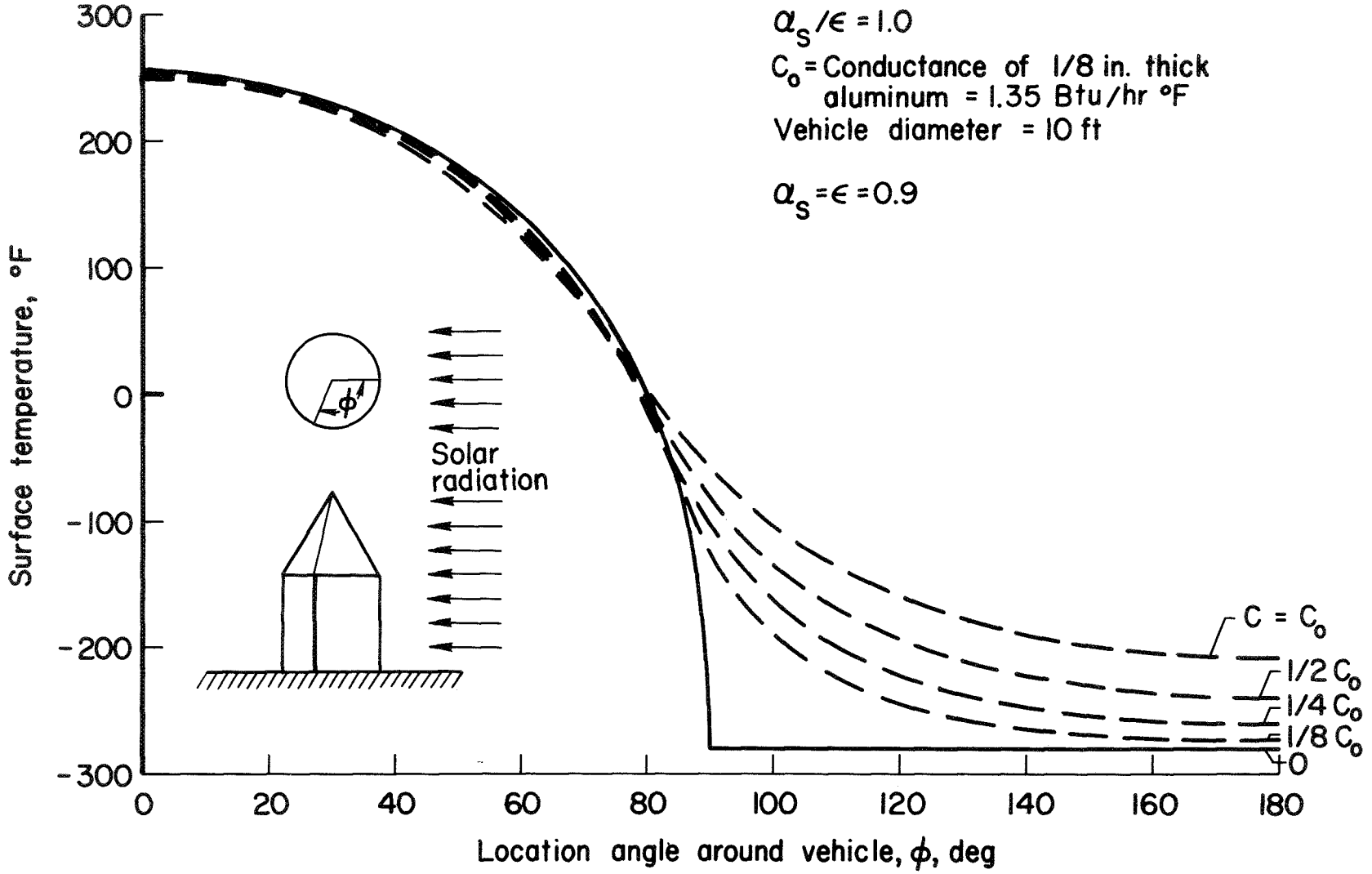
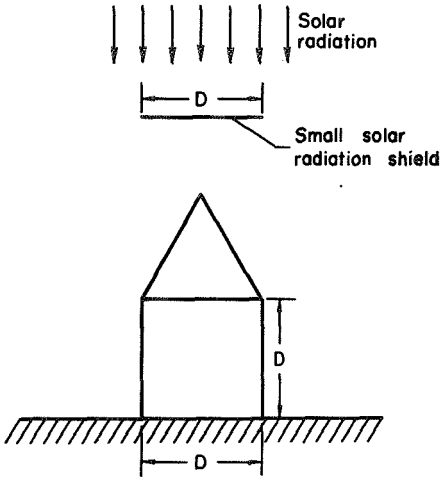
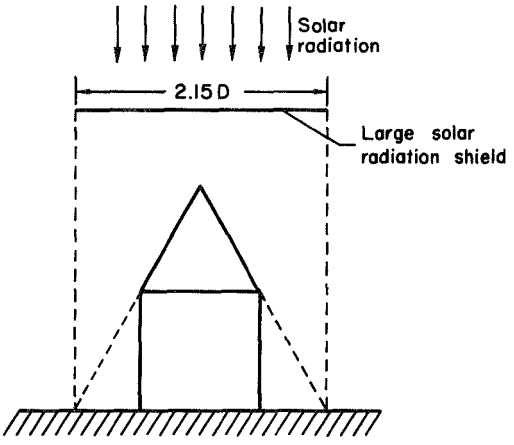


Figure 5. - Effect of thermal conductance upon the temperature variation around the cylindrical section of the vehicle when illuminated from the side; no internal heat.

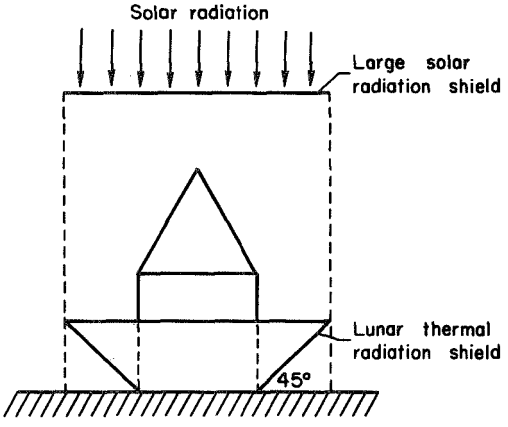
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
AMES RESEARCH CENTER, MOFFETT FIELD, CALIFORNIA



(a) Small solar shield



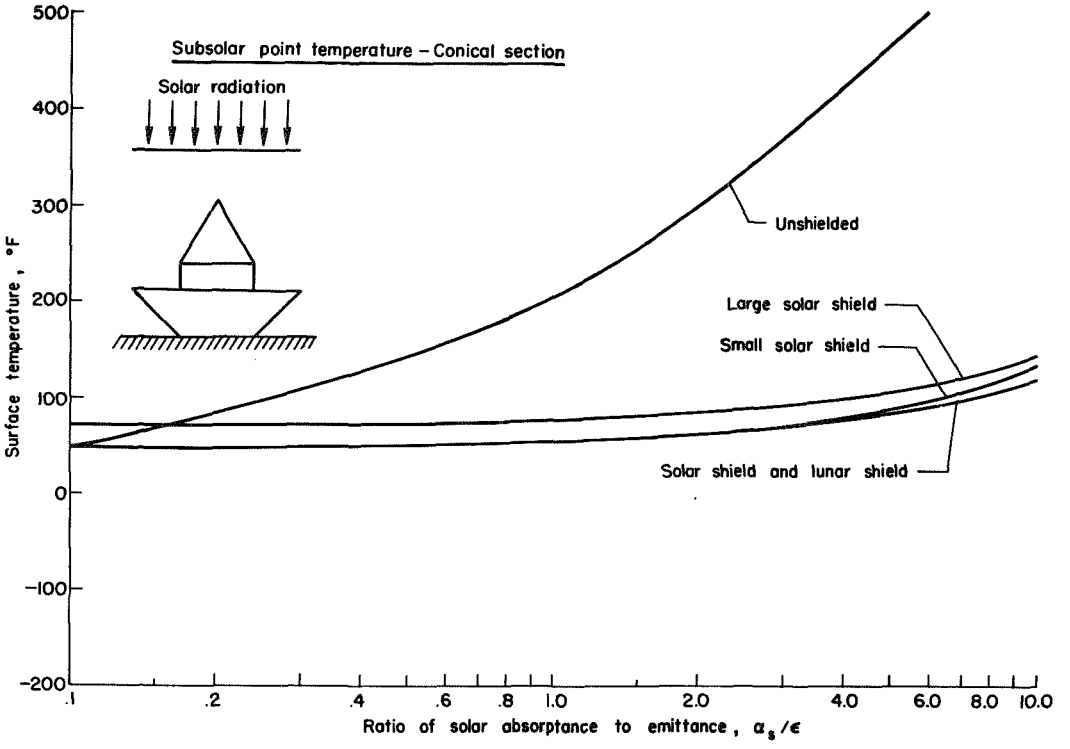
(b) Large solar shield



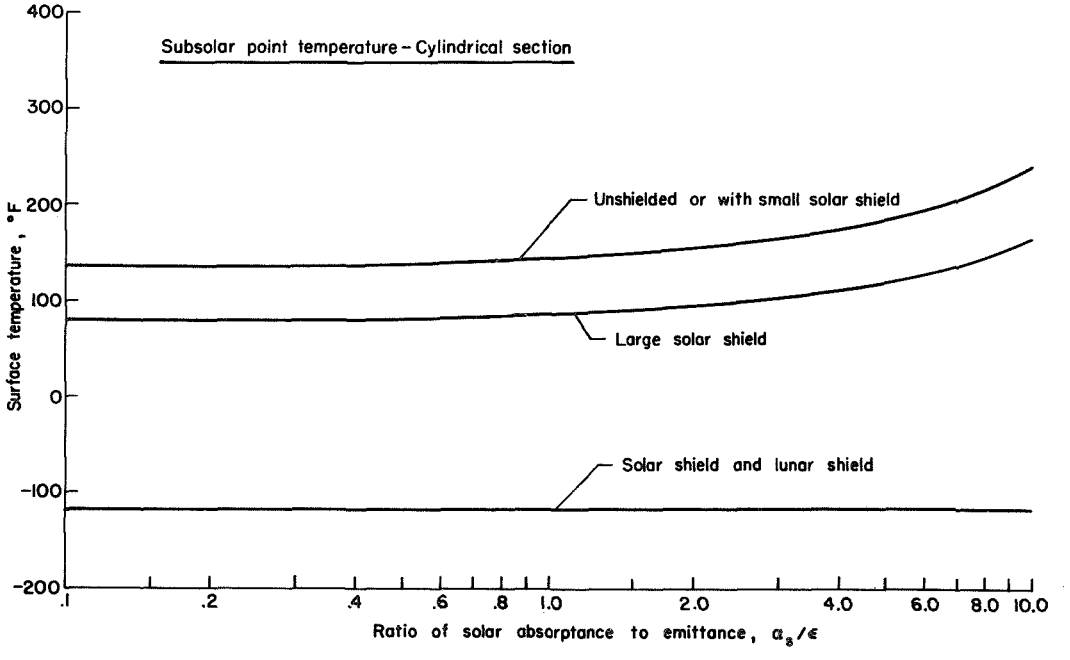
(c) Solar shield and lunar shield

Figure 6. - Shielded vehicle configuration

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
AMES RESEARCH CENTER, MOFFETT FIELD, CALIFORNIA



(a) Conical section



(b) Cylindrical section

Figure 7. - Effectiveness of solar and lunar radiation shields at the subsolar point as a function of the α_s/ϵ ratio on the vehicle; conductance and internal heat both zero.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
AMES RESEARCH CENTER, MOFFETT FIELD, CALIFORNIA

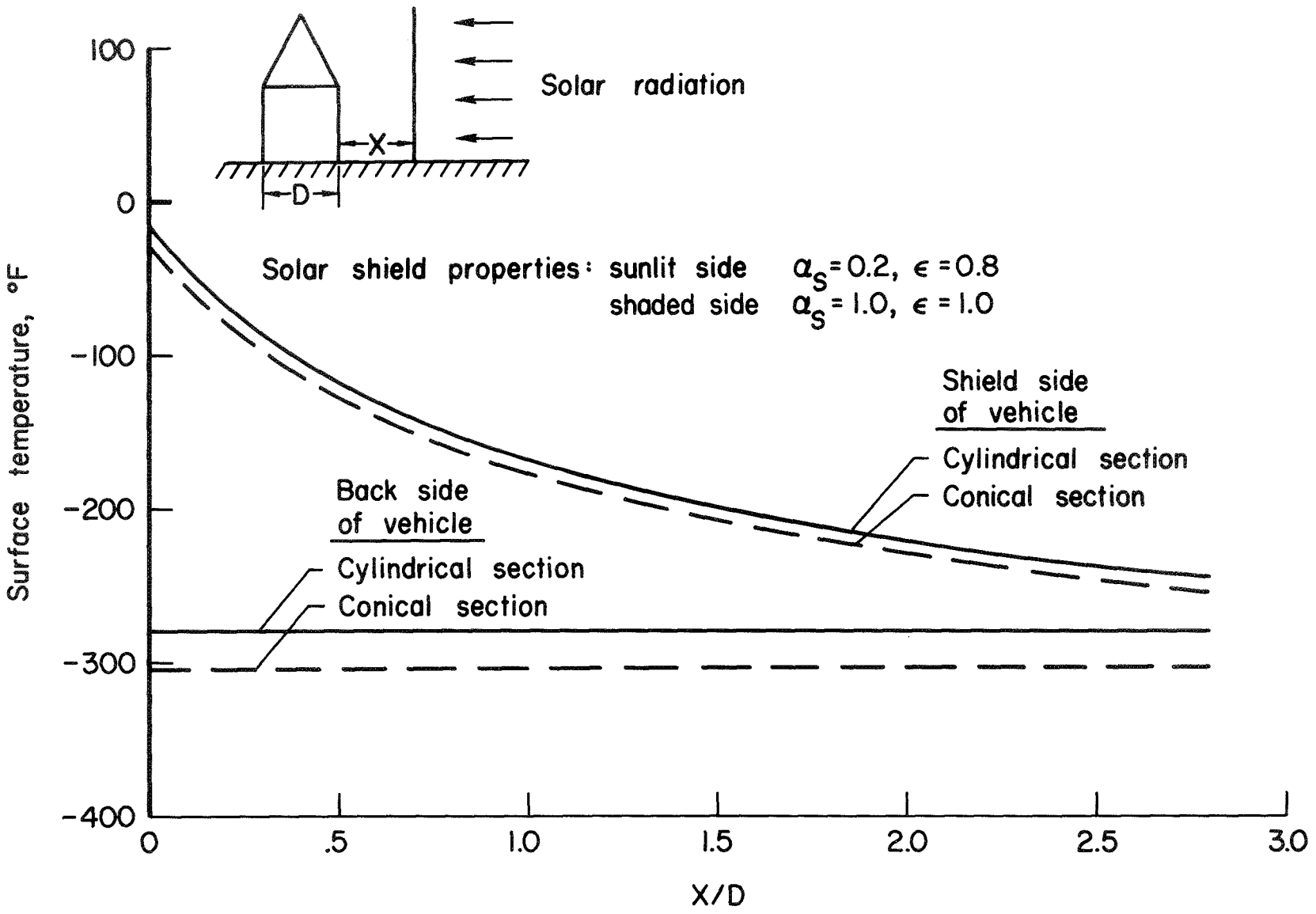


Figure 8. - Effectiveness of a solar-radiation shield when the vehicle is illuminated from the side; conductance and internal heat both zero.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
AMES RESEARCH CENTER, MOFFETT FIELD, CALIFORNIA